

Ships' sea-chests: an overlooked transfer mechanism for non-indigenous marine species?

Ashley D.M. Coutts^{a,*}, Kirrily M. Moore^{b,2}, Chad L. Hewitt^{b,3}

^a Australian Maritime College, Fisheries and Marine Environment, P.O. Box 21, Beaconsfield, Tasmania 7270, Australia

^b Centre for Research on Introduced Marine Pests, CSIRO Marine Research, Hobart, Tasmania 7001, Australia

Received 14 May 2003; received in revised form 1 June 2003

Keywords: *Carcinus maenas*; *Corbula gibba*; Hull fouling; Non-indigenous marine species; Port Phillip Bay; Sea-chests

Historically, hull fouling associated with slow-moving, wooden-hulled vessels has been recognized as the primary transport mechanism responsible for the dispersal of non-indigenous marine species (NIMS) around the world and the fouling of hulls may have contributed significantly to the current patterns of biogeographic distributions of many marine organisms (e.g., Carlton and Hodder, 1995). Over the past three decades however, ballast water has been identified as the primary causal mechanism and has been the focus of international concern (e.g. Carlton, 1985; Thresher, 1999; Eldredge and Carlton, 2002). Recent studies (e.g., Cranfield et al., 1998; Thresher et al., 1999; Hewitt, 2002; Gollasch, 2002) suggest that the attachment of organisms on the hulls of vessels remains a significant vector in modern times, possibly equal to ballast water, although further conclusive evidence is required. Currently, there is no concerted effort to evaluate the relative importance of these disparate mechanisms in the transfer of NIMS to new locations.

The discussion of transfer mechanisms has identified that numerous locations within and on a vessel may afford distinct environments (e.g., Rainer, 1995; Carlton, 1996; Coutts, 1999). Carlton et al. (1995) discussed sea-chests (sea inlet boxes, or suction bays) as environments linked with hull fouling assemblages. Similarly, Gollasch (2002) has discussed the role of sea-chests in the transport of fouling organisms. Sea-chests provide a unique part of the vessel for the transport of marine organisms, dissimilar to ballast water and the exposed surface of the hull.

Sea-chests are recesses built into a ships hull located beneath the waterline on the side and/or on the bottom near the engine room. They are designed to reduce water cavitation, and thus increase pumping efficiency when seawater is pumped aboard the vessel for engine cooling, ballast, and fire fighting purposes. The size, number and dimensions of sea-chests vary considerably with vessel size and type. As a general rule, the larger the vessel, the increasing demand for ballast water, the greater the size and number of sea-chests. Sea-chests are protected by metal grates, which have holes (15–25 mm in diameter) or slots (20–35 mm width) to prevent foreign matter entering and damaging the ships pumps. These grates are held in place by a number of bolts, and therefore sea-chests are usually only accessible during dry-docking.

In order to ascertain the extent to which sea-chests provide a unique habitat and contribute to the transport of NIMS, we undertook a preliminary investigation of the passenger ferry *Spirit of Tasmania*, which operates in southeastern Australia. The hull of the *Spirit of Tasmania* was surveyed for fouling at the Australian Defence Industries Limited dry-dock at Garden Island, Sydney, on 15 July, 1997. Fouling organisms were collected from various locations of the hull, including inside sea-chests using a paint scrapper and pre-labeled plastic bags and preserved in a 5% formalin and seawater mix. Specimens were later identified at CSIRO, Centre for Research on Introduced Marine Pests (CRIMP), Hobart, Tasmania.

The *Spirit of Tasmania* has three sea-chests located on the flat bottom (one on the port side and two on the starboard side). Each sea-chest is approximately 2 m high by 3 m wide, and covered by grates with approximately 20 mm holes. Sea-chests were accessed via a ladder and representative samples of fouling organisms collected and preserved.

The *Spirit of Tasmania* is a 14,129 dead weight tonnes (DWT) passenger and roll-on roll-off freight ferry, which travels between Devonport, Tasmania and Melbourne, Victoria, every two days. Thus, the vessel

* Corresponding author. Tel.: +64-3-5482319; fax: +64-3-5469464.

E-mail address: ashley.coutts@cawthron.org.nz (A.D.M. Coutts).

¹ Present address: Marine Biosecurity, Cawthron Institute, Private Bag 2, Nelson, New Zealand.

² Present address: Aquenal Pty Ltd., GPO Box 828, Hobart, Tasmania 7001, Australia.

³ Present address: Ministry of Fisheries, P.O. Box 1020, Wellington, New Zealand.

spends approximately 10 h a day (42%) in port and the remaining 14 h (58%) cruising between ports at an average speed of 18 knots. The vessel had been previously dry-docked in August 1995 at Forgacs floating dry-dock, Newcastle, New South Wales, and her hull coated with a tributyltin (TBT) self-polishing copolymer (SPC) anti-fouling paint (Internationals “Interswift” BKA007/8). No underwater scrubbing had been employed between successive dry-dockings.

Inspection of the hull revealed that the majority of the submerged area was relatively clean, while large accumulations of macro-fouling (the cryptogenic blue mussel *Mytilus edulis*, the introduced bryozoan *Watersipora subtorquata*, the native barnacles *Elminius modestus* and *Balanus variegatus* v. *cirratus*, the cryptogenic serpulid polychaete *Hydroides norvegica* and the native solitary ascidian *Pyura stolonifera*) were found in areas protected from strong laminar water flows (e.g. bow thrusters, undersides of bilge keels, inside ballast tank drain holes, and sea-chests) or areas lacking anti-fouling paint (e.g. docking blocks).

The entrances of intake pipes within sea-chests were dominated by large clumps of *M. edulis*, *H. norvegica*, and the hydroid *Ectopleura* sp., with accompanying epifauna consisting of barnacles *E. modestus* and *B. variegatus* v. *cirratus*, the erect bryozoans *Bugula* spp., and crustaceans *Halicarcinus* sp. and *Caprellid* sp. A number of large polychaetes (Onuphidae) ($n > 20$ individuals), the introduced European clam, *Corbula gibba* (>50) and three introduced adult European green crabs, *Carcinus maenas* were found in amongst mud in the bottom of the sea-chests. One *C. maenas* was found in each sea-chest, comprising one male and two ovigerous females. Specimens of *C. gibba* measured approximately 13.5 mm (shell length) and the *C. maenas* measured approximately 80 mm (carapace width).

Even though the *Spirit of Tasmania* is in constant trade, is relatively fast and is coated with a relatively effective anti-fouling paint, areas protected from strong laminar water flows were capable of harboring biologically significant accumulations of macro-fouling. Moreover, sea-chests provided a unique environment for a number of NIMS including two recognized Australian pest species; *C. gibba* and *C. maenas*, which were absent in other locations on the hull. The water flow within areas protected from strong laminar water flows is often inadequate for SPC anti-fouling paints to work effectively; therefore fouling organisms are able to colonise these areas and reach sexual maturity, which would not normally occur on the “mainstream” areas of the hull (Lewis, 2002).

C. gibba is native to the eastern Atlantic and the Mediterranean and was first detected in Port Phillip Bay in 1991 (Currie and Parry, 1996). Port Phillip Bay was probably the source of recent translocations of this species to Portland, Victoria (Parry et al., 1997) and Dev-

onport, Tasmania (Martin et al., 1996). Ballast water has been believed responsible for the introduction of this species to Australia (Boyd, 1999). Considering sea-chest gratings on most vessels usually exceed 15 mm and *C. gibba* grows to a maximum of about 15 mm in shell length (Currie et al., 1999), the ballast pumps of vessels containing bottom-facing sea-chests, such as the *Spirit of Tasmania*, are easily capable of vacuuming adult specimens of the species from the seabed during ballasting at low tides. More importantly, the species has the ability to escape from sea-chests and thus these structures may be responsible for the translocation of adult populations.

C. maenas is native to Europe and is now present throughout most parts of Victoria and Tasmania (Furlani, 1996). It was first recorded in Australia at the turn of the century in Port Phillip Bay (Fulton and Grant, 1900), although the species was probably introduced by wooden sailing ships servicing the gold rushes of the 1850s (Thresher et al., 1999). It likely survived the voyage by living deep inside old shipworm burrows (Chilton, 1911; Walters, 1996). Sea-chests could be considered the modern day counterpart of shipworm burrows in that they offer a similarly protected environment (Carlton et al., 1995).

The *C. maenas* adults found in the sea-chest of the *Spirit of Tasmania* undoubtedly entered the sea-chests as juveniles. They subsequently grew to a size sufficient to make escape impossible, possibly after feeding on resident bivalves, isopods, and barnacles. Although the crabs were too large to escape through the sea-chest gratings, two females were ovigerous, indicating that they were capable of releasing viable zoea. Like all brachyuran crabs, female *C. maenas* have a special pouch-like structure enabling them to retain viable sperm for up to a year and spawn fertile egg masses several times from a single mating (Hedgpeth, 1993). Hence, sea-chests are a potential dispersal mechanism for this species.

Other NIMS may have been introduced to Australia, or translocated within Australia via sea-chests. A third pest species in Australia, the northern Pacific seastar, *Asterias amurensis* has been detected in sea-chests and may have been translocated to Port Phillip Bay by vessels trading between Hobart and Geelong (K. Murphy pers comm.). Similarly, the gobiid fishes *Acanthogobius flavimanus*, *A. pflaumi*, and *Tridentiger trogonocephalus* may have been introduced and spread via eggs spawned inside sea-chests in Australia (Hoese, 1973; Lockett and Gomon, 1999) and New Zealand (Walsh et al., 2003).

Sea-chests of international cruise liners in particular should be considered a serious biosecurity risk due to the potential transfer of NIMS to highly sensitive marine environments. Such vessels visit pristine locales such as world heritage sites and transit ports all over the globe. Furthermore, given the adoption of the International Convention on the Control of Harmful Anti-fouling Systems on Ships (2001) which bans the use of

TBT anti-fouling paints on all vessels by 1 January 2008 in the absence of environmentally effective alternatives, the biosecurity risks of sea-chests are likely to increase.

To this end, since 1999, Cawthron Institute, New Zealand, have been sampling the sea-chests of vessels (500–6000 DWT) slipped and dry-docked in Nelson, Lyttelton and Auckland, New Zealand to determine the range of organisms being carried in sea-chests. Cawthron Institute and Pacifica Shipping (1985) Limited are also investigating methods of reducing the infestation of fouling in sea-chests, including an assessment of the efficacy of impressed current cathodic protection systems on three of Pacificas New Zealand coastal vessels.

Acknowledgements

The assistance of Blair Robertson, Felicity McEnulty, Nicole Mays and Nick Murfet with the identification of fouling organisms is gratefully acknowledged. TT-Line Company Priority Limited and Australian Defence Industries Limited, Robert Armstrong in particular for granting us permission to access the dry-dock to survey the *Spirit of Tasmania*. A special thank you to the New Zealand Foundation for Research Science and Technology for supporting the development of this manuscript. Useful comments on a draft manuscript were provided by Michael Taylor and Tim Dodgshun (Cawthron Institute).

References

- Boyd, S., 1999. The introduced mollusca of Port Phillip Bay. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), *Marine Biological Invasions of Port Phillip Bay*, Victoria. CSIRO Centre for Research on Introduced Marine Pests, Hobart, Australia. Technical Report # 20. pp. 129–149.
- Carlton, J.T., 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Oceanography and Marine Biology: Annual Review* 23, 313–371.
- Carlton, J.T., 1996. Pattern, process, and prediction in marine invasion ecology. *Biological Conservation* 78, 97–106.
- Carlton, J.T., Hodder, J., 1995. Biogeography and dispersal of coastal marine organisms: experimental studies on a replica of a 16th Century sailing vessel. *Marine Biology* 121, 721–730.
- Carlton, J.T., Reid, D.M., van Leeuwen, H., 1995. Shipping study: the role of shipping in the introduction of non-indigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options. US Coast Guard, Connecticut, Department of Transportation, Washington, DC. pp. 1–213.
- Chilton, C., 1911. Notes on the dispersal of marine crustacea by means of ships. *Transactions and Proceedings of New Zealand Institute* 43, 108–131.
- Coutts, A.D.M., 1999. Hull fouling as a modern vector for marine biological invasions: investigation of merchant vessels visiting northern Tasmania. Unpublished Masters Thesis, Australian Maritime College, Launceston, Tasmania, Australia. 283 pp.
- Cranfield, H.J., Gordon, D.J., Willan, R.C., Marshall, B.C., Battershill, C.N., Francis, M.P., Nelson, W.A., Glasby, C.J., Read, G.B., 1998. Adventive marine species in New Zealand. National Institute of Water and Atmospheric Research, Wellington, New Zealand. Technical Report # 34. 48 pp.
- Currie, D.R., Parry, G.D., 1996. The effects of scallop dredging on a soft sediment community: a large scale experimental study. *Marine Ecology Progress Series* 134, 131–150.
- Currie, D.R., McArthur, M.A., Cohen, B.F., 1999. Exotic marine pests in Port of Geelong, Victoria. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), *Marine Biological Invasions of Port Phillip Bay*, Victoria. CSIRO Centre for Research on Introduced Marine Pests, Hobart, Australia. Technical Report # 20. pp. 227–246.
- Eldredge, L.G., Carlton, J.T., 2002. Hawaiian marine bioinvasions: a preliminary assessment. *Pacific Science* 56 (2), 211–212.
- Fulton, S.W., Grant, F.E., 1900. Note on the occurrence of the European crab, *Carcinus maenas*, Leach, in Port Phillip Bay. *Victorian Naturalist* 17 (8), 147–148.
- Furlani, D.M., 1996. A guide to the introduced marine species in Australian waters. CSIRO Centre for Research on Introduced Marine Pests, Hobart, Australia. Technical Report # 5.
- Gollasch, S., 2002. The importance of ship hull fouling as a vector of species introductions into the North Sea. *Biofouling* 18 (2), 105–121.
- Hedgpeth, J.W., 1993. Foreign Invaders. *Science* 261, 34–35.
- Hewitt, C.L., 2002. The distribution and biodiversity of tropical Australian marine bioinvasions. *Pacific Science* 56 (2), 213–222.
- Hoese, D.F., 1973. The introduction of the gobiid fishes *Acanthogobius flavimanus* and *Tridentiger trigonocephalus* into Australia. *Koolewong* 2 (3), 3–5.
- International Convention on the Control of Harmful Anti-fouling Systems on Ships. 2001. Text can be found at <<http://www.ea.gov.au/coasts/pollution/antifouling/pubs/convention.pdf>>.
- Lewis, J., 2002. Hull fouling as a vector for the translocation of marine organisms. Phase 1 study—hull fouling research. Notting Hill, Victoria, Australia: AMOG Consulting. Report No.1, vol. 1. Submitted to Department of Agriculture, Fisheries and Forestry, Australia. 129 pp.
- Lockett, M.M., Gomom, M.F., 1999. Occurrence and distribution of exotic fishes in Port Phillip Bay. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), *Marine Biological Invasions of Port Phillip Bay*, Victoria. CSIRO Centre for Research on Introduced Marine Pests, Hobart, Australia. Technical Report # 20. pp. 283–295.
- Martin, R.B., Hewitt, C.L., Rainer, S., Campbell, M.L., Moore, K.M., Murfet, N.B., 1996. Introduced Port Survey of Devonport, Tasmania. CSIRO Centre for Research on Introduced Marine Pests, Hobart, Australia. Port Survey Report # 1.
- Parry, G.D., Currie, D.R., Crookes, D.P., 1997. Exotic marine pests in Portland Harbour and environs. Marine and Freshwater Resources Institute, Technical Report # 1. pp. 1–20.
- Rainer, S.F., 1995. Potential for the introduction and translocation of exotic species by hull fouling: a preliminary assessment. CSIRO Centre for Research on Introduced Marine Pests, Hobart, Australia. Technical Report # 1. 19 pp.
- Thresher, R.E., 1999. Key threats from marine bioinvasions: a review of current and future issues. In: Pederson, J. (Ed.), *Marine Bioinvasions, Proceedings of the First National Conference*, 24–27 January. Massachusetts Institute of Technology, Sea Grant College Program, Boston, Massachusetts. pp. 24–34.
- Thresher, R.E., Hewitt, C.L., Campbell, M.L., 1999. Synthesis: Introduced and cryptogenic species in Port Phillip Bay. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), *Marine Biological Invasions of Port Phillip Bay*, Victoria. CSIRO Centre for Research on Introduced Marine Pests, Hobart, Australia. Technical Report # 20. pp. 283–295.
- Walsh, C., Morrison, M.A., Middleton, C., 2003. Invasion of the Asian goby, *Acentrogobius pflaumii*, into New Zealand, with new

locality records of the introduced bridled goby, *Arenigobius bifrenatus*. New Zealand Journal of Marine and Freshwater Research 37, 105–112.

Walters, S., 1996. Ballast water, hull fouling and exotic marine organism introductions via ships—a Victorian study. Environment Protection Authority, Victoria Publication 494. 143 pp.

0025-326X/\$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/S0025-326X(03)00292-3

Marine debris ingestion by Southern Giant Petrels and its potential relationships with fisheries in the Southern Atlantic Ocean

Sofía Copello^{a,*}, Flavio Quintana^{a,b}

^a Centro Nacional Patagónico (Conicet) Boulevard Brown S/N, 9120 Puerto Madryn, Chubut, Argentina

^b Wildlife Conservation Society Southern Boulevard 2300, Bronx, 10460 New York, USA

The quantity of litter in the world's oceans has been steadily increasing over the years. Within the Southern Ocean, the amount of debris increased 100-fold during the early 1990s (Barnes, 2002) and fisheries appear to be the greatest single source (Burton and Riddle, 2001). The composition of floating debris has become dominated by anthropogenic plastics and polystyrenes, metals and glass (Burton and Riddle, 2001).

Seabirds ingest floating plastics and other foreign matter while feeding on the surface of the ocean (Ryan, 1987). The prevalence of plastic ingestion by seabirds has increased and is well documented in many families of Procellariiformes (Bourne and Imber, 1982; Ryan et al., 1988; Kinan and Cousins, 2000). The Southern Giant Petrel (*Macronectes giganteus*) is a wide ranging procellariiform which breeds in the coasts of Patagonia and forages throughout the Argentine continental shelf (Quintana and Dell Arciprete, 2002), and which often interacts with fisheries activities. Little is known about their diet and their extent of marine debris ingestion. To date, there is only one published reference of ingestion of marine debris by Southern Giant Petrel from Marion island at the Subantarctic Ocean (Nel and Nel, 1999). Here we evaluate the presence of marine debris in the diet of Southern Giant Petrels chicks at a colony on the Patagonian coast.

The study was conducted at Isla Arce (45°00'S, 65°50'W) on the Patagonian shelf, Argentina, in the South Atlantic Ocean, where about 350–400 Southern Giant Petrels breed annually (Yorio et al., 1998). As part of a wider study concerning the foraging ecology of Southern Giant Petrel, between 29 January and 4 April 2002 a total of 73 food samples were taken from 73

randomly selected chicks. Samples were obtained by upending chicks over a bucket plastic and massaging the stomach and throat. The sample was strained, the liquid drained off and all the samples preserved in 70% alcohol for later analysis. In the laboratory, each sample was thawed and drained, the remaining solid components were removed, and the presence and absence of different marine debris items computed. The litter were categorized as plastic (including plastics bags, caps, etc), plastic lines, vegetables (including peel of onions, potatoes, corn cob), aluminum foil, paper, wood and others (including rubber foam, wire, rope and styrofoam). Each item was weighed to the nearest 0.01 mg using a digital balance. Frequency of occurrence (FO) refers to the number of samples in which a particular item appeared.

Seventy three percent of food samples ($n = 73$) contained marine debris. Plastics were by far the most frequent item (FO = 66%), followed by plastic line (36%) and vegetables (34%). Other items such as aluminum foil, wood, paper and others were less frequent (less than 15%) (Cochran's test $Q = 129.9$, $df = 9$, $p < 0.0001$) (Fig. 1). We extracted a total of 70.1 g of debris from the chicks' stomachs, composed by 37.0 g of plastics, 11.8 g of paper, 10.1 g of vegetables and 5.4 g of aluminum foil. The lightest items were wood, plastic lines and others items (all less than 1 g). The average weight of litter in each sample was 2.0 ± 3.4 g ($n = 73$).

The results indicate a high proportion of marine debris in the diet of Southern Giant Petrels from Isla Arce, plastics being the most frequent items. The literature on marine debris leaves no doubt that plastics make-up most of the marine litter worldwide, ranging between 60 and 80% of the total waste disposal at sea (Derraik, 2002). Although there have been several studies on the diet of *Macronectes* spp. in Subantarctic colonies (e.g. Hunter, 1983; Hunter and Brooke, 1992; Ridoux, 1994), the occurrence of marine debris has not been previously

* Corresponding author. Tel.: +54-2965-451024; fax: +54-2965-451543.

E-mail address: scopello@cenpat.edu.ar (S. Copello).